JOURNAL

of

STEEL CASTINGS RESEARCH

CONTENTS

A Simplified Method for Determining Riser Dimensions . . 2

Waterglass—CO_2 Process for Hardening Molds and Cores . 10

Properties of TS-8130 Cast Steels 13

STEEL FOUNDERS' SOCIETY OF AMERICA

NUMBER 1 JANUARY 1955

TECHNICAL RESEARCH COMMITTEE, SFSA

H. D. PHILLIPS, Adirondack Foundries & Steel, Inc.
CHAIRMAN

E. H. BERRY, Dodge Steel Company

C. K. DONOHO, American Cast Iron Pipe Company

F. X. HOHN, Scullin Steel Company

C. B. JENNI, General Steel Castings Corporation

G. A. LILLIEQVIST, American Steel Foundries

R. A. WILLEY, Commercial Steel Casting Company

C. H. WYMAN, Burnside Steel Foundry Company

V. E. ZANG, Unitcast Corporation

DIRECTOR OF RESEARCH AND JOURNAL EDITOR
CHARLES W. BRIGGS

Copyright 1955
by
Steel Founders' Society of America

920 Midland Building **Cleveland 15, Ohio**

PURPOSE OF THE JOURNAL

Issue No. 1 of the Journal of Steel Casting Research is made available through its authorization by the Board of Directors, Steel Founders' Society. It is the present plan to publish this Journal about every four months—or three times a year—and it will consist of approximately sixteen printed pages with a cover.

The Technical Research Committee of the Society asked the Board of Directors that a journal on steel casting research become a regular publication of the Society. The Committee was of the opinion that there were many items of importance concerning recent developments and new findings in the production of steel castings which should be brought together and forwarded to the member companies so as to keep them abreast with the very latest developments going on in the world which relate to steel castings.

The Journal will contain, from time to time, papers or reports covering some phases of, or relating to, one of the research reports previously published by the Technical Research Committee of the Society. It is the hope that member companies who have derived considerable benefit by adopting the results of a report will present their findings as they apply to their operations. It is also hoped that when the members of the staff of other member companies read these testimonials of what can be accomplished, they will likewise devote themselves to further application of the research reports.

Also, it is hoped that some companies will go beyond the scope of the Society's published research and that the Journal can carry a resume of their studies and findings. The leadoff paper in this issue of the Journal is in this category. Research Report No. 13 on the calculation of riser diemensions was published in July 1947. It contained a formula method for carrying on these calculations. However, the calculations have been considered time consuming and they have not been universally used throughout the industry. The leadoff article, by members of the staff of the Naval Research Laboratory, consists of a simplified method of riser calculations following the principles of Research Report No. 13.

The Research Journal will also contain experimental results of Society studies, as directed by the Technical Research Committee, which could better be treated informally rather than through the medium of a formal blue book research report. For example, during the Korean emergency certain alloys were restricted and for awhile certain ones were very difficult for the steel foundry industry to secure. At that time there was pressure from the industry for the Society to study the properties of certain low-alloy substitute steels. A project was prepared but the Society was unable to get the foundries to produce the steels because of excessive requirements and other reasons. However, the steels finally were secured and the tests made. In the meantime the necessity for these steels no longer existed and the studies could not be considered as strictly fundamental research, but the results should be made available to the industry for possible further use. Therefore, in this issue of the Journal there is appearing a portion of the findings on Research Project No. 34—"Substitute Cast Steels."

The Journal will also contain resumes of published information concerning new developments applicable to steel castings. These developments may be made in the U.S.A. or in other countries of the world.

An example of this type of coverage is presented in the article in this issue on the use of sodium silicate and CO_2 to produce molds and core for steel castings.

The Journal will also carry, when space is available, resumes of reports prepared by the British Steel Casting Research Association, Steel Castings Institute of Canada, and the Central Research Laboratory of France, on steel casting subjects. Reports from these countries will be distributed to the steel casting industry when they are available to SFSA for publication, the reports will be summarized to present the practical information that could be helpful to our industry.

From time to time the Journal will contain progress reports concerning the various SFSA research projects so that the accomplishments may be followed by the member companies.

Also, the Journal will include short miscellaneous items of a research or development nature that can be looked upon as news items, which will require further substantiation and study before all the facts are available.

All steel foundrymen are invited to prepare articles for the Journal. Information on what your company has accomplished in the use of research reports is very much desired. The length of the article is of no consideration. One that consists of only a few paragraphs will be as much appreciated as one of more extended treatment. Also, if some news item on steel casting research comes to your attention, send it along to the Editor; do not make the mistake of thinking that this information is already in his hands. Let everyone get busy and look for and prepare material on steel casting research for future Journal publication thereby assisting in the forward movement of the steel casting industry.

The publication will be distributed, for the present at least, to the same mailing list which receives the Research Reports, and in the same quantity. Additional copies may be secured by writing to the Editor. There is no charge for the publication. It comes to you as another of the many services provided you by Steel Founders' Society of America.

A SIMPLIFIED METHOD FOR DETERMINING RISER DIMENSIONS

*by H. F. Bishop, T. E. Myskowski and W. S. Pellini**

Introduction

Risers contribute to casting soundness by supplying liquid feed metal to compensate for liquid to solid shrinkage and by promoting directional solidification within the casting. Risers must be positioned in such a manner that all portions of the casting are within the feeding range of a riser; if this is not done centerline shrinkage will develop within the casting. Riser dimensions must be such that the riser solidifies more slowly than the casting and provides a sufficient quantity of feed metal to satisfy the feed metal requirements of the casting; if the riser is inadequate in either of these two respects underriser shrinkage will develop in the casting. In order to obtain maximum casting yield the riser dimensions must not be excessive and the risers must not be located too close together. The ideal in risering is to employ risers having dimensions so that the riser pipe just reaches the casting and to position the risers in a manner so that their maximum feeding range is utilized.

Until recently risering was almost entirely an art based upon the experience of the foundryman, since there were no quantitative data on positioning and dimensioning of risers. However, in the last few years several papers have been published which provide numbers and rules as guides. Reports by the authors [1-4], and SFSA Report No. 30 [5], have described the distances risers can feed to complete soundness in cast steel bars, plates and joined plates of dissimilar thickness and data have been presented to show the extent to which casting edges and chills can be utilized to increase the feeding range of risers. SFSA Report No. 13 [6] provided a basis of scientific dimensioning by reducing the problem of choosing optimum riser sizes to mathematical formulae, but his method has the disadvantage of requiring numerous calculations. The present study was undertaken to simplify the SFSA method for choosing risers of optimum dimensions and to extend the method to cases of complicated castings. The Steel Founders' Society's original contribution is acknowledged by the authors as the basis for the work reported herein.

Methods

In the first part of the investigation, cube, bar and plate castings of different sizes were cast of Navy class B steel having a nominal composition of .20 to .30 percent carbon, .40 to .60 percent silicon and .60 to .80 percent manganese. All heats were given a final deoxidation treatment by the addition of .10 percent of aluminum to the ladle and were poured at temperatures of 2950 to 2975 degrees F. The castings were fed with risers of various diameters and heights. In all cases a mildly exothermic anti-piping compound was used as a cover. Riser adequacy was determined by X-raying a one inch thick vertical section removed from the center of the riser and the casting section immediately below it.

The riser diameters and heights were varied until the minimum riser volume which would bring the pipe tip to the riser-casting contact line was determined. With experience, it was found that the minimum height could be established exactly by subtracting from the riser height the distance by which the tip of the riser pipe missed the riser-contact line. This procedure provides an accurate estimate if the "miss" is not in excess of 1 to 2 inches. Considerable time was saved by this procedure after its validity was established.

The second part of the investigation consisted of a study of the risering procedures for more complex castings such as bushings and joined sections of dissimilar shape and thickness. The same procedures for determining minimum riser sizes were followed.

Determination of Minimum Riser Diameters

There are two factors which must be considered concurrently in choosing correct riser dimensions for a given casting: (1) the riser must have an adequate freezing time and (2) the riser must have an adequate volume. An adequate freezing time means that the riser must stay partially molten until after the casting solidifies. If the riser freezing time is inadequate (riser freezes earlier than the casting because of inadequate diameter) underriser shrinkage will occur in the casting even though a very large riser volume is provided by the height dimension. Conversely, if the freezing time is sufficient but the riser volume is inadequate, underriser shrinkage will again occur.

Since the freezing time of a riser must be in excess of the freezing time of the casting which it feeds, the diameter of a suitable riser will be related to the solidification time of the casting. When a mildly exothermic anti-piping compound is used, the freezing time of a riser is approximately proportional to the square of its diameter, i.e., acts thermally as if it were of semi-infinite length. The freezing time of a cast section of a given shape increases proportionately to the square of its thickness in the same manner that the freezing time of a riser

* Metallurgical Division, Naval Research Laboratory, Washington, D. C.

increases proportionately to the square of its diameter. For this reason it is possible to express riser diameters, for certain simple shapes, in terms of casting thickness (T). For example, it is known that long plates require a minimum of 2.5T risers which means that if the plate is 2 inches thick the riser should be 5 inches in diameter, or if the plate is 6 inches thick the riser should be 15 inches in diameter. The ratios of freezing time of the riser to freezing time of the casting will be the same in each case.

The direct relationship of casting thickness and freezing time applies to castings having the same shape, i.e., the same relative thickness, length and width dimensions. Thus, a casting with dimensions of 2 x 4 x 6 inches has the same shape as one of 4 x 8 x 12 or 6 x 12 x 18 inches. However, when the length and/or width of a casting is sufficient to provide for "semi-infinite" conditions of a solidificaton, further increases in length and/or width do not change the freezing time. Thus, for castings in this category freezing times are related directly to thickness regardless of length and/or width dimensions. The significance of the term "semi-infinite" has been discussed previously. Briefly, this means a length and/or width which provides for maximum freezing time. A bar of approximately 5T length is semi-infinite from a thermal viewpoint because increasing the length does not increase the freezing time.

Castings of the same thickness but of different shapes can have markedly different solidification times due to variations in their volume to surface area ratios. The reason for this may be understood more easily from the illustration of Fig. 1 which shows the conditions under which a cube shaped, unit volume of metal of thickness T freezes when it is part of castings having the same thickness but different shapes. The cube as a complete casting can lose heat to the mold thru all six of its faces and hence solidifies rapidly. The minimum diameter riser which will have an adequate freezing time to feed the cube has been determined, Table I, to be one having a diameter of 1.1 times the cube thickness (1.1T)*.

The same volume as the unit cube located at the center of a bar casting having cross sectional dimensions of T x T can lose heat to the mold thru only 4 of its faces and its solidification time is increased by a factor of 2.5 over that of the integrally cast cube. The riser on a bar casting hence must have a correspondingly longer freezing time which is obtained by means of a 1.6T diameter riser, (Table I).

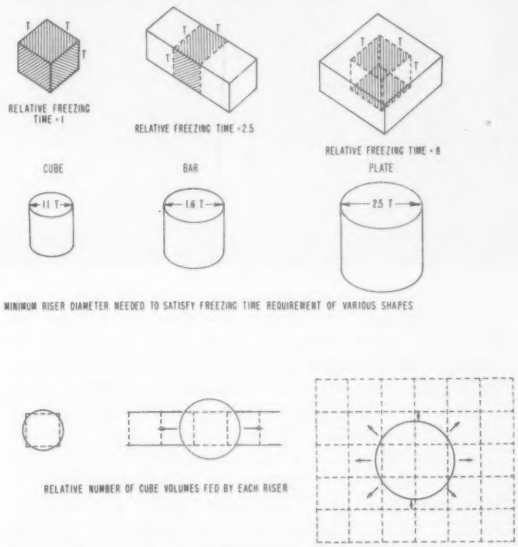

RELATIVE FREEZING TIME = 1
RELATIVE FREEZING TIME = 2.5
RELATIVE FREEZING TIME = 8
CUBE
BAR
PLATE
1.1 T
1.6 T
2.5 T
MINIMUM RISER DIAMETER NEEDED TO SATISFY FREEZING TIME REQUIREMENT OF VARIOUS SHAPES
RELATIVE NUMBER OF CUBE VOLUMES FED BY EACH RISER

Figure 1—A unit cube solidification in various shapes.

When the same volume of metal is at the center of a plate shape, Fig. 1, it can lose heat thru only two faces and as a result the solidification time of this same volume is increased by a factor of 8 over that of an integral cube. The riser on a plate shape must have a diameter of at least 2.5 times the plate thickness (2.5T), in order to develop an equivalent slow rate of solidification. The cube in these illustrations serves to point out that the same volume of metal located in different shapes will have different freezing times and therefore the riser freezing times must be matched.

TABLE I—Riser/Casting Volume (R_V/C_V) as a Function of Riser Height/Diameter (H/D).

Casting Dimen.-in.	$\frac{L+W}{T}$	Riser D.-in.	Riser H.-in.	Riser H/D	Vol. Riser cu. in.	Vol. Cast. cu. in.	R_V/C_V	Casting Condition
4x40x4	11	5	20	4	390	640	.61	NG
12x12x2	12	4	11	2.7	140	290	.48	NG
4x40x4	11	6	14	2.3	395	640	.62	OK
24x25x4	12.2	10	13	1.3	1020	2400	.42	OK
12x12x2	12	5	5	1.0	98	290	.34	OK
12x12x2	12	6	3½	.6	99	290	.34	OK
24x25x4	12.2	13	6½	.5	865	2400	.36	OK
4x4x4	2	4½	7	1.5	110	65	1.7	OK
4x4x4	2	5	3	.6	59	65	.92	OK
4x4x4	2	6	1½	.25	42	65	.66	OK

* For practical use, SFSA has determined by research report No 13, a value of 1.15T.

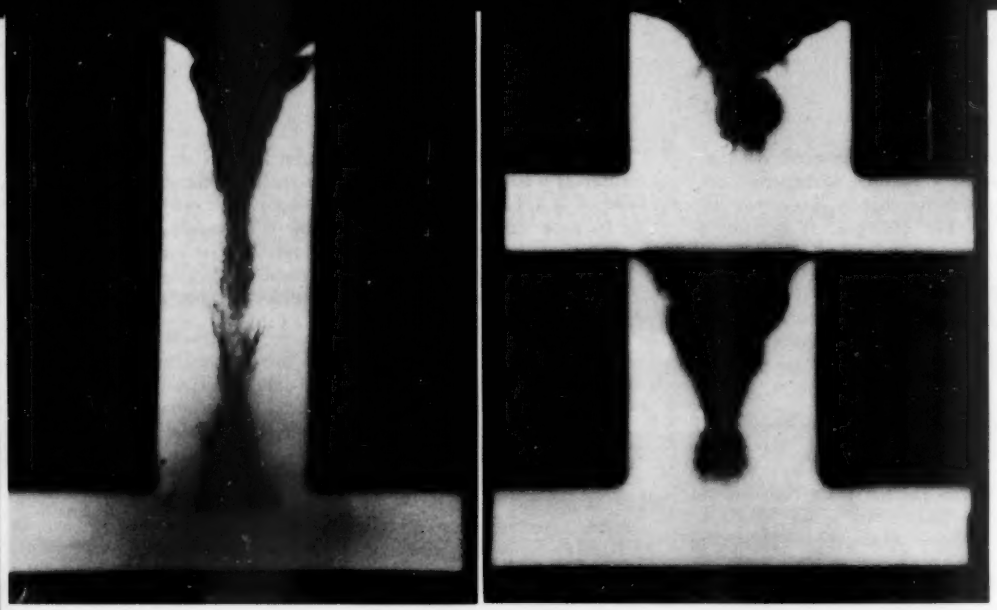


Figure 2—Radiographs of transverse sections through risers and portions of a 12x12x2 inch plate. Riser dimensions:

Left —
4″ diameter, 11″ high

Upper Right —
6″ diameter, 4″ high

Lower Right —
5″ diameter, 5″ high

Fig. 2 illustrates the condition of soundness resulting in "semi-infinite" 12 x 12 x 2 inch plate castings fed with risers having different diameters. The 5 inch diameter riser is the minimum which can be used on this casting without the occurrence of under-riser shrinkage. It may be noted that shrinkage occurs below the 4 inch diameter, 11 inch high riser even though its volume is greater than that of the 5 inch diameter, 5 inch high riser. The appearance of the shrinkage at the riser-casting junction in this system indicates that the hot spot, or point of final solidification, is within the casting. Thus the 4 inch diameter riser, regardless of its height, could not completely feed this casting. The 6 inch diameter 4 inch high riser completely feeds the plate since its solidification time is in excess of the required minimum provided by the 5 inch diameter riser.

Thermal studies on bar and plate castings have indicated that the chilling effect of a casting's edge extends into the casting for a distance of approximately 2.5T and accelerates freezing times over this distance. At greater distances from the casting extremities heat is lost only thru the lateral faces and solidification in these regions occurs essentially as though the casting were of infinite length for the case of the bar, and of infinite length and width for the case of the plate. The riser thermal effect extends for approximately 1.5 to 2T. Thus a bar casting with a riser at one end and a casting end at the other must be at least 5T long to contain a semi-infinite zone.

In this study a plate casting is defined as one having a length and width of at least 5T and a bar casting is defined as one having a symmetrical cross section with a length of at least 5T so that in each case the center of the casting is beyond the influence of edge or end effects. The minimum riser diameters quoted in the previous paragraphs apply to bars and plates of any length exceeding these minimum dimensions.

"Semi-bar" sections which have lengths less than 5T solidify at shorter times because all locations in the castings are within the region of influence of the casting extremities. Because of their shorter solidification times "semi-bars" can be fed by risers with diameters of less than 1.6T, but always greater than 1.1T (diameter required for a cube, i.e., the shape which is approached as the bar is made shorter).

Similarly "semi-plate" castings which have one or both of the lateral dimensions between 1T and 5T solidify at times less than those of a true plate, but always at longer times than a bar of thickness T, and require risers with minimum diameters between 1.6T (true bar) and 2.5T (true plate). It should be noted that as a plate is reduced in one of its lateral dimensions a bar shape is approached. The minimum riser diameters needed to adequately supply feed metal to such intermediate shapes are indicated by the curve of Fig. 3.

The significance of Fig. 3 is that the two limiting shapes are a plate and cube. A true plate (W and L both either 5T or greater) requires 2.5T diameter risers. Insofar as freezing time is concerned it makes no difference how much greater than 5T the plate dimensions are because freezing time is not increased. As one dimension of the plate is decreased below 5T a bar shape is approached and therefore the shorter freezing time of a true bar is approached; this permits use of risers of shorter freezing time (less diameter than for true plate).

Insofar as freezing time is concerned it makes no difference how long the bar is in excess of 5T and therefore the minimum diameter riser applicable for a true bar can be used to provide sufficient freezing time. As the bar length is shortened below the 5T length the freezing time of a cube is approached and therefore smaller diameter risers provide sufficient freezing time. Nothing has been said about riser

volume to this point in order to present a clear picture of the solidification time factor in risering. Volume considerations will be discussed in the section to follow.

Determination of Minimum Riser Volumes

Despite the fact that a plate casting requires a larger minimum diameter riser than a bar of the same thickness and a bar requires a larger minimum diameter riser than a cube of the same thickness, casting yield is greater for a plate casting than for a bar, and greater for a bar than for a cube. The reason for this is apparent from a consideration of the illustrations at the bottom of Fig. 1 where it may be noted that while a riser on a cube casting can feed only that cube, a riser on a bar feeds a number of such unit cube volumes and a riser on a plate feeds a still greater number of units. In other words as the section becomes more rangy, the ratio of volume of riser to volume of casting decreases because the riser serves more units insofar as providing liquid metal for the "time" required by the casting as a whole.

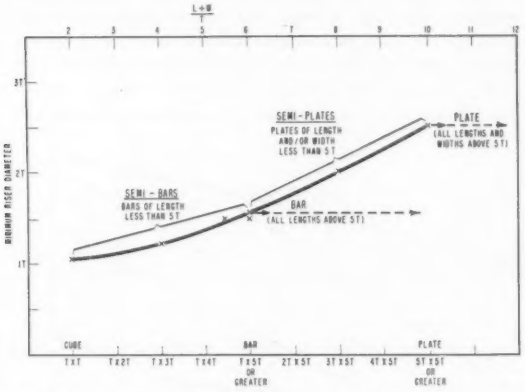


Figure 3—Minimum riser diameters required for simple casting shapes.

The metal lost by solidification in the riser wall decreases yield - in the case of plates the loss is a small percentage of the total volume because of the great number of unit volumes involved, while in the case of a cube the loss is a large percentage of the total volume because only one unit is involved. While the riser size required for the unit volume of the cube is actually smaller in absolute size (number of cubic inches) than that for a riser on a plate of equal thickness, in terms of percentage of the casting volume the riser volume for the plate is considerably smaller. Thus, the amount of metal which is "lost" by solidification in the riser is progressively a smaller percentage of the casting volume as the casting shape is changed from a cube, to semi-bar, to bar, to semi-plate and finally to a true plate. It is possible, however, that a long bar could have the same number of unit volumes as a relatively small plate in which case the efficiency of the risers on the two castings would be equal.

It should be recognized that the "time" of final freezing required of a riser for a given casting is determined by the ratio of surface area to volume of the casting. This is defined as the "shape factor" of the casting. Castings with large surface to volume ratios freeze rapidly and conversely castings with small surface to volume ratios freeze slowly.

Recent solidification studies by the authors have shown that the calculation of relative freezing times from geometric shape provides exact information for simple shapes (true cubes, bars and plates) if suitable constants specific to the shape are used; for semi-bars and semi-plates the information is only approximate and for highly complex castings it is erroneous. Actually SFSA's methods apply to the case of simple and some moderately complicated shapes by virtue of the fact that the relationships are empirical, i.e., experimentally determined for castings of various shape factors. Thus, any simple expression of the casting shape related empirically to riser requirements should serve equally as well as the cumbersome V/SA ratios.

It has been found in this investigation that the shape factor of a simple casting can be described by a simple relation of the length, width and thickness of the casting, $SF = (L+W)/T$ and this serves as the basis of the proposed simplification of the SFSA's risering method. The significance of this modification is that the time consuming SA/V calculations may be replaced by simple $(L+W)/T$ calculations without affecting the end result, i.e., the accuracy of determining riser size. In addition the new method permits extension of the system to include determination of minimum riser sizes for complex castings containing joined sections of different sizes and shapes which is not possible by the SA/V calculation approach. In the proposed system a cube always has a shape factor of $(T+T)/T$, or 2, irrespective of the actual value of T. A plate having dimensions of 25 x 25 x 2 inches has a shape factor of $(25+25)/2$, or 25, a bar of dimensions 4 x 4 x 16 inches has a shape factor of $(4+16)/4$, or 5, etc.

The minimum riser dimensions were determined experimentally for a variety of simple shapes, and those having riser height to riser diameter ratios between .5 and 1.0 are shown in Fig. 4 as a plot of shape factor versus riser volume expressed as a fraction of the casting volume. The plot is restricted to risers of this range because:

(1) Risers having heights greater than their diameter are inefficient since additional metal is lost by solidification against the additional riser surface, thus reducing casting yield.

(2) Risers having heights of less than half their diameter, while having a high degree of efficiency were considered to be impractical. Such risers re-

quire the use of diameters which are very large for the castings involved. The added cleaning costs and close control required in pouring make such risers undesirable. (Note 1)

Table I presents data on risers of various height to diameter ratios which illustrate the desirability of restricting riser geometry to the H/D ratios presented in Fig. 4. Also shown in Fig. 4 are riser

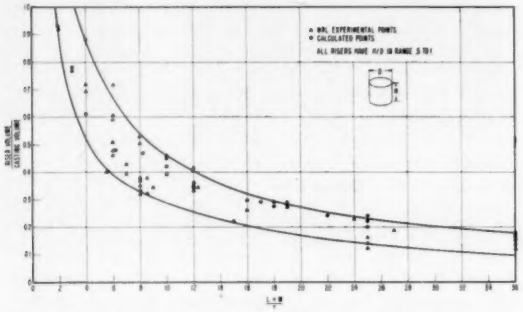


Figure 4—Relation of casting shape factor to minimum effective riser volume as a fraction of casting volume.

volumes required for a variety of simple shapes as calculated by the SFSA's method [6]. Riser volume to casting volume ratios were determined according to SFSA's procedures and plotted vs. the (L+W)/T of the castings. The experimentally determined points and the calculated points are in close agreement and fall within a relatively narrow band thus indicating a check with SFSA Report No. 13 experimental data based on castings poured at various foundries and also the validity of employing the simple (L+W)/T shape factor to replace the cumbersome freezing ratio,

$$\frac{\text{S.A. Riser}}{\text{V. Riser}} \div \frac{\text{S.A. Casting}}{\text{V. Casting}}$$

, as a coordinate for expressing the shape factor of the casting.

Variations of the experimental points between the upper and lower limits of the band result from foundry variables which are not always subject to exact control. In adapting this method of choosing risers to any particular foundry it is recommended that risers first be chosen which correspond to the top region of the band. If by experience it is indicated that the riser volumes are excessive, the riser volume to casting volume ratios can be lowered or "shaped" on subsequent castings. By such preliminary experimentation a line within the band will be established which will indicate the most efficient riser volumes for the practices used in that particular foundry.

To facilitate the translation of riser volume determined by Fig. 4 into riser dimensions, the chart of Fig. 5 was developed which interrelates riser height, riser diameter and riser volume. The upper and lower curved lines on the chart connect points

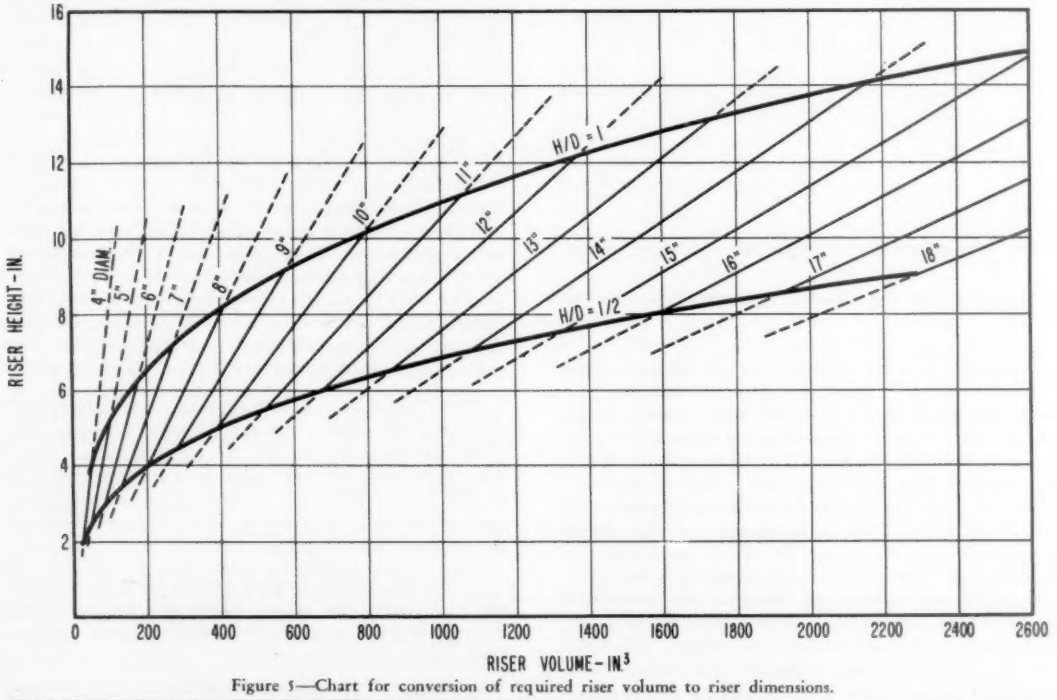


Figure 5—Chart for conversion of required riser volume to riser dimensions.

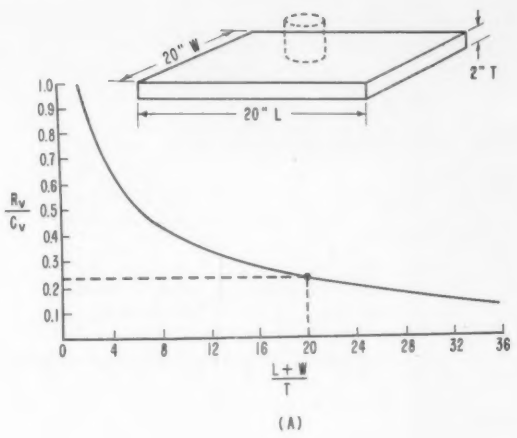
Note 1—Riser heights employed in the industry are from 1.0 to 2.5 times their diameter with a 1.5 value used most frequently. This point should be kept in mind during the review of this Article.—The Editor.

representing riser heights equal to 1 and to ½ times the riser diameter respectively; hence all points within the band represent the most efficient and practical riser shapes. It has been observed from the many castings risered according to this system that when the riser volume, as indicated on the shape factor chart, is obtained with risers having dimensions such as fall within the band of Fig. 5, the riser diameter is always sufficient to fulfill the freezing time requirement. When properly used, the two charts of Figs. 4 and 5 automatically resolve both of the time (minimum riser diameter) and the riser volume factors discussed previously.

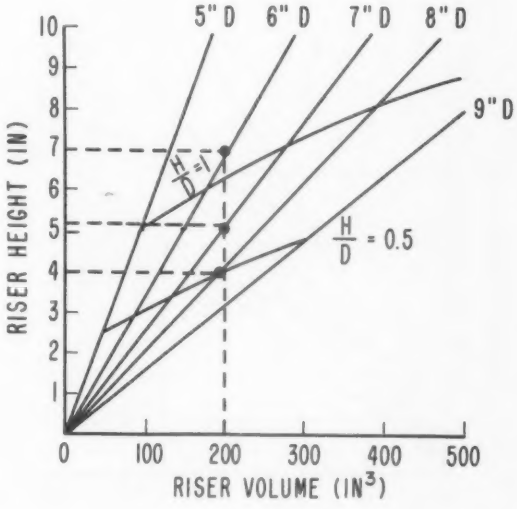
Figs. 6 and 7 illustrate the method of choosing risers for simple plate and bar castings according to the proposed system. At the top of each of these figures is reproduced the shape factor chart (which is shown as the midpoint line within the band) and the riser dimensioning chart. The (L+W)/T factor of the plate casting in Fig. 6 is 20. Referring to the shape factor chart at the top of this illustration it can be noted that the riser needed on this casting must have a volume which is .25 of the plate volume or 200 cubic inches. On the middle chart it is found that this volume can be obtained with risers of the following dimensions: 6 inches in diameter and 7 inches high, 7 inches in diameter and 5¼ inches high, and 8 inches in diameter and 4 inches high. The first of these risers has a height slightly in excess of its diameter and falls outside of the band; thus either the 7 or the 8 inch diameter riser should be used for this casting.

Similarly the 5 x 5 x 30 inch bar casting, Fig. 7, has a (L+W)/T factor of 7 which indicates that the riser volume must be .5 of the casting volume or 375 cubic inches. The riser dimension chart shows that either a riser 8 inches in diameter and 7½ inches high, or a riser 9 inches in diameter and 5½ inches high should be used for this casting.

The correct riser dimensions for castings requiring multiple risers can be determined by figuratively dividing the casting into segments to be fed by each riser and then following the same procedure for each segment as previously described for integrally risered castings. Sample calculations for the case of two risers on a 32 x 20 x 2 inch plate are shown in Fig. 8. Since each riser will feed half of the plate, the (L+W)/T factor is determined for only half of the plate and thus is 18. The calculations show that each of the risers must be 6 inches in diameter and 6 inches high. Similarly if 3 or 4 risers are to be employed on a uniform casting, the volume of each riser is based upon the shape factor of a one-third or one-fourth, of the casting. The portion of the casting fed by each riser in these cases may not be confined to the exact dimensions used to calculate the (L+W)/T factor, but for purpose of calculating riser dimensions this assumption can be made.



(A)



(B)

$$\frac{L+W}{T}=\frac{20+20}{2}=20$$

$$\frac{R_V}{C_V}=0.25 \text{ (A)}$$

$C_V = 20 \times 20 \times 2 = 800 \text{ in}^3$

$R_V = 800 \times .25 = 200 \text{ in}^3$

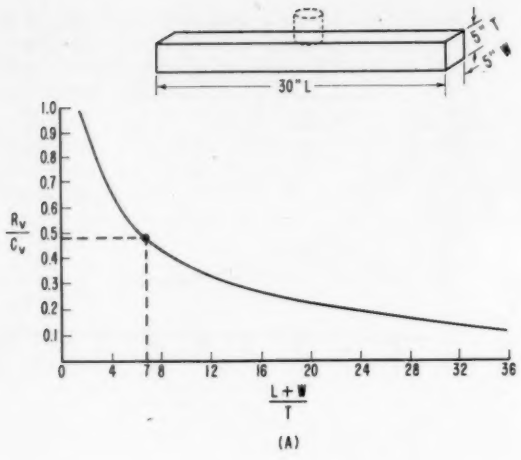
Risers with Vol = 200 in³ (B)

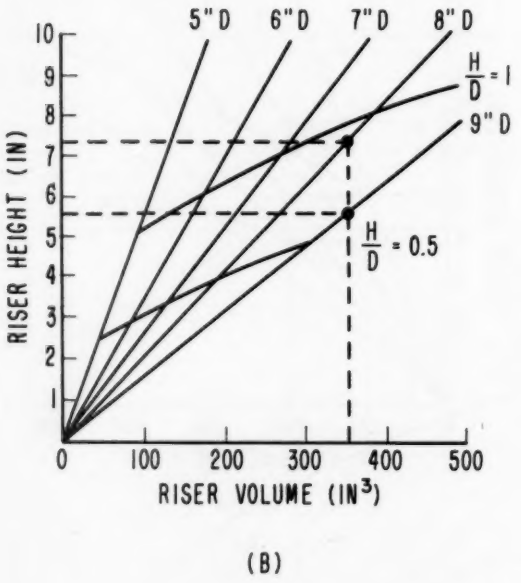
6" D x 7" H

7" D x 5¼" H

8" D x 4" H

Figure 6—Procedure for determination of minimum riser for a plate casting.





$$\frac{L+W}{T} = \frac{30+5}{5} = 7$$

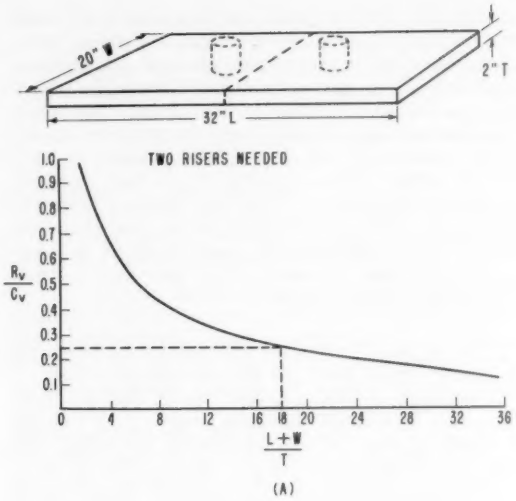
$$\frac{R_V}{C_V} = 0.5 \text{ (A)}$$

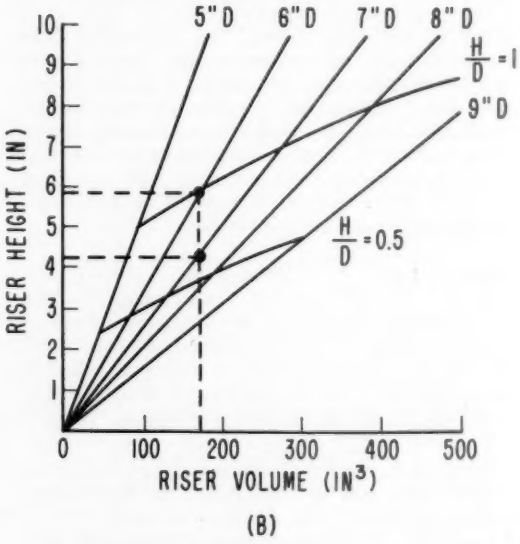
$C_V = 30 \times 5 \times 5 = 750 \text{ in}^3$

$R_V = 750 \times 0.5 = 375 \text{ in}^3$

Riser with Vol. = 375 in^3 (B)
8" D x 7½" H
9" D x 5½" H

Figure 7—Procedure for determination of minimum riser for a bar casting.





EACH RISER

$$\frac{L+W}{T} = \frac{16+20}{2} = 18$$

$$\frac{R_V}{C_V} = 0.25 \text{ (A)}$$

$C_V = 16 \times 20 \times 2 = 640 \text{ in}^3$

$R_V = 640 \times 0.25 = 160 \text{ in}^3$

Riser with Vol. = 160 in^3 (B)
6" D x 6" H
7" D x 4½" H

Figure 8—Procedure for determination of minimum risers for castings requiring more than one riser.

Many times, when the casting shape is irregular, it will be necessary to make approximations in arriving at a (L+W)/T factor. Fig. 9 for example shows a ring casting which was risered according to the principles described. It was approximately 200 inches in circumference and had the irregular cross section indicated in the drawing. For purpose of calculating the shape factor the cross sectional dimensions were assumed to be 5 inches in width and 3 inches in thickness. Because of feeding range requirements it was decided to feed the casting with 8 risers and locate chills midway between adjacent risers to increase the riser feeding range. This would require that each riser feed a 25 inch long segment of the ring. The following calculations were made to determine the dimensions of each of the 8 risers:

Cross sectional area of the casting = 15 sq. in.

C_V per riser = 15 sq. in. x 25 in. = 375 cu. in.
$(L+W)/T = (25+5)/3 = 10.0$
R_V/C_V (From Fig. 4) = .45
R_V = .45 x 375 cu. in. = 170 cu. in.
Riser having volume of 170 cu. in.
(From Fig. 5) = 6 in. Diameter
6 in. High

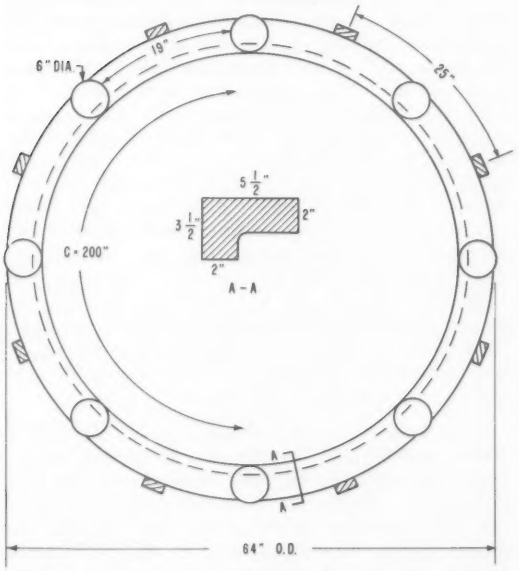


Figure 9—Ring casting risered according to proposed system.

It can be noted from Fig. 4 that for a (L+W)/T factor of 10 the band encompasses a range of R_V/C_V ratios of .3 to .45. Since this particular shop casting was urgently needed and because of the fact that the dimensions were approximated, the factor at the top of the band was used for riser calculations in order to minimize the chances of under-riser shrinkage. The ring was sound and the X-ray of a slice removed from the center of one of the risers, showed that the pipe extended to about ¾ inch from the casting (Fig. 10).

Figure 10—Sound casting of the ring shown in Figure 9 with X-ray of a slice of riser.

As indicated earlier this risering method purports to show only the minimum riser which can be employed to prevent under-riser shrinkage. If the casting is to be made sound, the rules pertaining to riser and chill locations must be followed. Consider for example the ring casting of

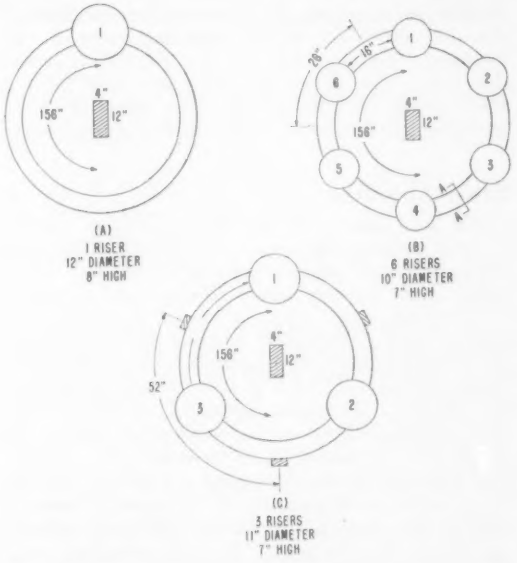


Figure 11—Ring casting made with different risering procedure.

Fig. 11, having a circumference of 156 inches, which can be made free of *under-riser shrinkage* by using either one, three or six risers of the dimensions indicated. The calculations employed in arriving at these riser dimensions follows:

A) Fed with one riser
Casting Vol. (Approx.) = Circumference x width x thickness = 156 x 12 x 4 = 7500 cu. in.

$$\frac{L+W}{T} = \frac{156+12}{4} = 42$$

R_V/C_V (Extrapolated from Fig. 4) = .12
R_V = .12 x 7500 cu. in. = 900 cu. in.

Riser Dimension (From Fig. 5) = 12 in. Diameter
8 in. High

(continued on page 12)

WATERGLASS - CO_2 PROCESS FOR HARDENING MOLDS AND CORES

There has been much interest of late in the possible use of molds and cores bonded with waterglass and hardened with CO_2. As long as twenty years ago experiments were being conducted in France with waterglass as a binder. However, experiments at that time met with little success. In 1948 a patent was granted in France which detailed the process of using waterglass as a binder and with the introduction of CO_2 a hard core or mold was produced immediately. Up to this date the process has never been successfully used in France. German improvements upon the basic principles may lead to a new process for making hard cores and molds without any baking or drying period necessary.

The process of hardening cores or molds consists of using silica sand bonded with waterglass (alkali silicates) and upon the injection of CO_2 into the molded sand mixture a silica gel forms and surrounds the sand grains and brings about hardening of the mixture. The length of time that the CO_2 is introduced into the molded sand mixture varies from a few seconds to minutes depending upon mold or core size considerations which will be discussed later.

Sand Mixture

The sand mixture of the German process consists of 94.5 percent silica sand, 4.7 percent waterglass binder, and 0.8 percent bituminous binder. Generally in the written accounts of this process reference is made to an asphaltic binder; however, it is believed that a bituminous additive such as sea coal would achieve the same results; or perhaps the cereal binders as normally used in steel molding sands may be sufficient. Successful application of this process has been achieved by using 5 percent sea coal as an additive for the production of cores for iron castings. The sand used in the hardening mixture should not be too coarse as the rounding of the grains, effectively done by the silica gel, may lead to difficulties and the problem of dirty castings. The mixture is thoroughly mulled in a conventional mixer. Although the molds and cores harden rapidly on the exposure of a commercial grade of CO_2, there is no fear of hardening by the small quantity of CO_2 that is present in the atmosphere. The mixture may be preserved over night after mixing by covering with a wet cloth.

Core Making

Patterns used in core making are the same as convential ones with the usual amount of draft. The drafts must be maintained because upon the introduction of the CO_2 into the molded mixture the sand slightly increases its volume. Sand for cores is lightly rammed or pressed into the corebox to compensate for the volume increase. The appearance of cracks on the core after the draw indicates that the draft is insufficient or else that the sand was rammed in too hard. Rodding or wiring in most cases can be done away with except when using arbors for handling and setting the core into the mold. After the core is rammed, the box is struck off and the core lightly knocked loose. A number of holes are made through the core and ending at the pattern surface by means of a chromium plated rod .12 to .20 inches in diameter. These holes are spaced 6 to 8 inches apart.

Blowing CO_2 into the Core

While the sand mixture is still in the core box CO_2 is blown into each one of the holes made with the use of a special nozzle which has a dozen openings at its lower end. The blow is made by inserting the nozzle in the holes until in contact with the pattern and starting the CO_2 flow. Carbon dioxide is introduced under a pressure of from 2 to 4 atmospheres (30 to 60 psi). The nozzle is drawn slowly out of the core until hardening is complete throughout the cores. During this stage use can be made of a moveable diaphragm fitted on the nozzle and large enough to cover the hole to help prevent the CO_2 from backing up and out of the holes. The diaphragm will help to force the CO_2 through the sand mixture. The amount of time necessary to complete hardening of an entire core may be only a matter of seconds but the amount of time necessary will be gained through experience. As an example, it took a core 50 x 50 x 10 inches, 120 seconds to completely harden; but a core that weighed 3½ tons needed 15 minutes to harden completely. At positions near the nozzle white spots will appear. These spots are indications of local supersaturation with CO_2. Experience will yield the necessary amount of time spent blowing each particular hole. Care should be taken so as not to inject an unduly large amount of CO_2 into the mold or core since it will be only a waste of the gas.

Immediately after the blowing period the core is drawn from its box. Any loose sand sticking to the box is an indication that the hardening process was incomplete. Either the holes were too far apart, the CO_2 injection time was too short, or else the pressure of the CO_2 supply was too low. The holes are then patched with the sand mixture and lightly touched with CO_2 to give an entire hardened core surface.

It is important that the CO_2 blown into the mold is dry; otherwise, extra amounts of water will be put into the sand core. The foundry temperature will have a direct effect on the blowing of CO_2 especially during the winter months. In the winter months when the air temperature is lowered, an electrically heated pressure gage is used on the tanks to enable the CO_2 to pass as a gas into the cores and to prevent the gas from forming dry ice flakes during the blowing cycle.

Core washes can be used but they must be free from water to avoid softening of the cores.

Molding

Sand used for molding is the same as the mixture given for cores. The only major difference is that the sand is used as a facing to give a partly hardened mold.

Because the mold is hardened before the pattern is drawn, the gating system must be included as a part of the pattern both in the drag and cope. In molding the drag, a 1¾ to 3 inch layer of the hardenable mixture is placed over the entire pattern and then the remainder of the box is filled up with the normal backing sand, rammed and struck off. Holes for the CO_2 are made in the same way as was discussed for the cores. Particular attention must be given to making these holes as they must extend through to the pattern so that the CO_2 may reach the hardenable mixture during blowing. The blowing cycle is the same as discussed for cores except that the nozzle needs to be drawn only from its starting position next to the pattern, to the end of the hardenable facing. The drag is then rolled over and the cope is molded and hardened. After complete hardening the pattern is drawn and all blowing holes are filled and hardened with a light touch of CO_2.

Loosening of the mold by rapping is generally not possible; therefore, the pattern must have sufficient draft to enable it to be drawn easily. The easiest type of casting made with this process is a cylinder cast horizontally.

Due to the fact that there is a considerable amount of water present as a portion of the hardened silica gel, it is very important that there be sufficient venting so that the steam generated upon pouring can escape through the mold.

Mechanical Properties

The mechanical properties of the hardened mixture and the effect of the blowing time upon these properties were examined by blowing CO_2 into several test cores. The test cores were made by ramming the mixture three times in a tube of two inches, inside diameter. Table I gives the results of the tests.

As seen in the table, treatment for only 15 seconds results in the core being hard enough to be set into a mold. Since the gas permeability shows equally good values of oil core and normal molding sand, no scabbing is expected to result if the hardening has been completed to the proper level.

Advantages

According to a German investigator an overall savings of 20 percent is the result of using the CO_2 process for small and medium sized cores as compared to the normal baking process. Table II compares the economic aspects of the oil sand with the CO_2 process.

TABLE I—Core Properties as a Function of CO_2 Hardening Time

Time of CO_2 Injection Seconds	Hardening Time Permeability No.	Shear Strength psi	Compression Strength psi
Start	150	0.57	1.56
1	170	0.86	1.56
2	170	0.86	1.71
5	170	1.00	1.99
10	170	2.58	3.70
15	175	10.2	30.6
20	182	22.6	46.2

TABLE II—Cost Comparison per 100 Pound Batch†

Oil Sand

2.5 lbs of core oil at $26.80 per 100 lbs. = $0.56

CO_2 Process

5 lbs. waterglass binder at $6.82 per 100 lbs. = $0.35

1 lb. bituminous binder at $3.20 per 100 lbs. = $0.03

1.5 lbs. of CO_2 at $5.50 per 100 lbs. = $0.08

$0.46

Assuming that it costs $.02 to dry 100 pounds of core sand, then cost considerations of the two processes per 100 lbs. of sand mixture are:

Oil Sand	$ .58
CO_2 Sand	$ .46

† German cost estimate converted to U. S. dollars.

Other expenditures such as additional equipment are negligible since very little equipment is needed. Production times are also lessened because cores and molds may be produced just prior to their use.

Since cores are hardened in their patterns, the problem of breakage during transportation to drying racks, and so forth, is lessened considerably.

Dimensional accuracy of the CO_2 process is one of the major advantages. As was mentioned previously, oil sand cores which are transported during their plastic stage have amounts of deformation that occur on protruding edges and vertical faces. This is very unfavorable. Other dimensional changes of the oil sand may occur during the drying period. Cores produced by the CO_2 process are hardened in the core box prior to drawing, and there are no dimensional changes that occur if the cores are handled properly. Because of the closer control on designed dimensions it is possible to eliminate machining after casting.

Much thought has been brought forward concerning the high strength values of the cores which may lead to difficult knockout problems. In the casting of steel this difficulty can be eliminated if sufficient amounts of bituminous binder are added and if the blow period is accurately timed.

The future outlook is excellent in adopting the CO_2 hardening process to core blowing operations. The compressed air used in this process may be partly replaced by CO_2 so the hardening of the core will occur immediately with the production of the core while in the machine. Cores can then be taken direct to the molding floor without providing for core plates or oven drying.

Disadvantages

Most of the disadvantages have been voiced by the Editor of the German foundry journal "Giesserei-Praxis". Generally, his feelings are against the use of the CO_2 hardening process:

> "This process has never been successfully employed in France because of the inherent disadvantages possessed by waterglass. On pouring, the molds and cores first became doughy but then set again and they can only be removed from the casting with a great deal of effort. The softening easily leads to faulty dimensions."

Thin walled castings readily crack and then the castings become scrap.

Since waterglass binder contains 10 to 12 percent alkali it is necessary that this sand must be separated from the rest of the sand system because the alkali may lower the sintering point of the system sand.

Conclusions

Up to the present time there is not enough material available to be able to state conclusively that the CO_2 hardening process is usable in the steel foundry industry. There is definitely one English and at least two German foundries that are successfully producing the CO_2 hardened molds and cores up to weights of several tons. The CO_2 process is in its infancy and much experimental work must be completed before any definite conclusions concerning this process may be drawn.

Shell molding has its definite advantages with certain applications. The relatively new CO_2 process may also find its way to molding and coremaking applications in the steel foundry.

Some of the disadvantages that have been presented appear to have a possible solution. With this idea in mind, foundry technology should move ahead in the use of a waterglass binder or some other binder that is very closely related.

BIBLIOGRAPHY

"Carbon Dioxide in Sand Creates Solid Molds", *Giesserei-Praxis*, Vol. 71, December 10, 1953, p. 418.

"Hardening Molds and Cores by Means of Carbon Dioxide" by W. Schumacher; *Giesserei*, Vol. 40, December 24, 1953, pp. 678-681.

"Making Cores and Molds by CO_2 Hardening", *Foundry Trade Journal*, August 12, 1954, p. 179.

"Carbon Dioxide Process for 'Baking' Molds and Cores" by H. J. Heine; *American Foundryman*, September 1954, p. 46.

Determining Riser Dimensions (continued from page 9)

B) Fed with 6 risers

$$\frac{L+W}{T} = \frac{\frac{156}{6}+12}{4} = 9.5$$

R_V/C_V (From Fig. 4) = .42

$R_V = .42 \times \frac{7500 \text{ cu. in.}}{6} = 525 \text{ cu. in.}$

Riser Dimension (From Fig. 5) = 10 in. Diameter
7 in. High

C) Fed with 3 risers

$$\frac{L+W}{T} = \frac{\frac{156}{3}+12}{4} = 16$$

$R_V/C_V = .27$

$R_V = .27 \times \frac{7500 \text{ cu. in.}}{3} = 672 \text{ cu. in.} = 675 \text{ cu. in.}$

Riser Dimensions = 11 in. Diameter
7 in. High

The ring made with one riser, although free of under-riser shrinkage, would have extensive internal shrinkage at the centerline of the ring since most of the casting is beyond the feeding range of the riser. However, if internal shrinkage could be tolerated and only a good surface appearance were required of this casting this would be the simplest and most economical way to make it since the required riser volume is only 12 percent of the casting volume. The casting of Fig. 11(B) fed with 6 risers located so that the distance between the periphery of adjacent risers is 4T (16 inches) would be internally sound since all regions of the casting are within the feeding range of a riser. However, the total riser volume needed is more than tripled as compared to the case where only 1 riser is used to feed the casting, (42 vs 12 percent of casting volume). By employing chills between risers to increase riser feeding range, Fig. 11(C), the casting can be made internally sound with only three risers having a total volume of 27 percent of the casting volume because the chills extend riser feed range sufficiently to permit all portions of the casting to be within the feeding range of the risers.

(To be continued in the next issue of the Journal.)

PROPERTIES OF TS-8130 CAST STEEL

In the past several years shortages of critical alloying elements for steels have occurred and at any time in the future it may again be necessary to use substitute alloy steels designed to conserve manganese, nickel, chromium and molybdenum. The Steel Founders' Society of America initiated an investigation (Research Project No. 34) to determine the properties of three new lean alloy steels in which the steel castings industry is interested. The properties of TS-8130 cast steel are presented in this review. Four different heats of this steel from four foundries were tested. The steels were made by four different processes: basic open-hearth, acid open-hearth, basic electric, and acid electric.

The steels were heat treated by: (1) normalizing and tempering at 1200°F, and (2) water quenching and tempering at 1000°F and 1200°F. The mechanical properties of the steel, including Charpy V-notch impact properties were compared. These data are supplemented by end-quench hardenability test results, and photomicrographs of the various heat treated structures.

In addition, some indication of the mass effect was obtained by taking test specimens from the approximate center of 4-inch heat treated sections of the acid electric heat.

Chemical Composition

The chemical compositions of the four different heats used in this investigation are listed in Fig. 1. Proposed SFSA chemical specification for the TS-8130 cast steel is carbon 0.30-0.37 percent; manganese 0.70 percent; silicon 0.30-0.60 percent; chromium 0.30-0.55 percent; nickel 0.20-0.40 percent; molybdenum 0.08-0.15 percent; sulfur, maximum of 0.05 percent, and phosphorus, maximum of 0.05 percent.

Mechanical Properties

The mechanical properties of TS-8130 cast steel are listed in Table I. It may be observed that the properties obtained by water quenching and tempering are superior to those obtained by normalizing and tempering. There do not appear to be any appreciable differences in the mechanical property data as obtained by the various steelmaking processes. There is a significant improvement in impact

CAST TS 8130

	STEEL MAKING PROCESS	C	Mn	P	S	Si	Ni	Cr	Mo	Norm. Temp. F°.	Quench Temp. F°.
O	Basic Open Hearth	.32	.70	.019	.019	.40	.40	.42	.10	1650	1575
X	Acid Open Hearth	.30	.75	.030	.039	.52	.41	.56	.14	1650	1575
□	Basic Electric	.28	.73	.023	.017	.47	.33	.39	.13	1650	1575
△	Acid Electric	.34	1.10	.035	.041	.30	.45	.40	.17	1650	1575

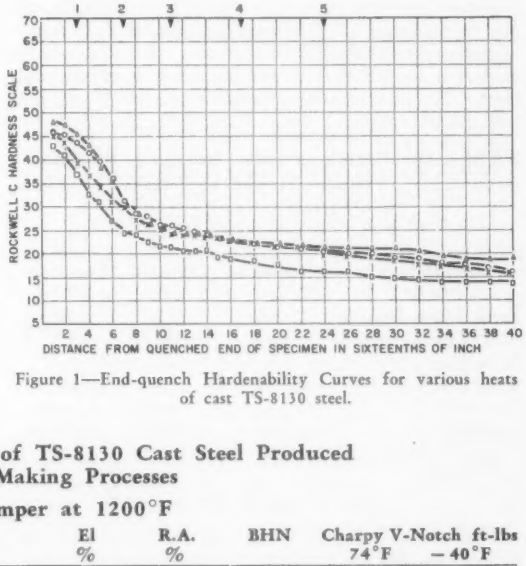


Figure 1—End-quench Hardenability Curves for various heats of cast TS-8130 steel.

TABLE I—Mechanical Properties of TS-8130 Cast Steel Produced by Various Steel Making Processes

Normalize and Temper at 1200°F

Steel Making Process	Tensile psi	Yield psi	El %	R.A. %	BHN	Charpy V-Notch ft-lbs 74°F	Charpy V-Notch ft-lbs −40°F
Basic Open-Hearth	95,000	57,400	24	46	192	28	13
Acid Open-Hearth	91,000	57,000	26	46	187	31	10
Basic Electric	90,500	55,500	26	52	187	42	19
Acid Electric	95,400	63,000	22	43	192	26	7
Average	93,000	58,000	25	47	190	32	12

Water Quench and Temper at 1200°F

Steel Making Process	Tensile psi	Yield psi	El %	R.A. %	BHN	Charpy V-Notch ft-lbs 74°F	Charpy V-Notch ft-lbs −40°F
Basic Open-Hearth	109,000	87,000	23	52	229	54	40
Acid Open-Hearth	111,000	90,000	23	50	229	39	36
Basic Electric	107,000	86,000	24	58	217	77	42
Acid Electric	114,000	96,000	18	43	235	25	23
Average	110,000	90,000	22	51	228	49	35

properties of the steel made by the basic processes which is explained by the fact that lower sulfur and phosphorus contents are possible when basic processes are employed instead of acid processes.

End-Quench Hardenability

The end-quench hardenability curves for the four heats indicate a relatively shallow hardening steel. A typical hardenability band is represented by the four heats in Fig. 1; the small differences in the hardenability curves are the result of variations in chemistry. It may be concluded that the hardenability curves of TS-8130 steel, as made by the four steelmaking processes, are similar and within a fairly narrow range.

Effect of Heat Treatment

Regardless of the steelmaking process the effect of heat treatment on the TS-8130 steel is the same.

Generally strength and strength-toughness values are improved when water quenching and tempering practices are employed as compared to normalizing and tempering. Of significance is the 20-25 percent increase in yield strength for similar tensile strength, of water quenched steel as compared to normalized steel. The yield-tensile strength ratios are illustrated in Table II.

TABLE II—Effect of Heat Tratment on Yield-Tensile Strength Ratios TS-8130 Cast Steel

Steel Making Process	Normalized & Tempered at 1200°F	Water Quenched Tempered at 1200°F	Water Quenched Tempered at 1000°F
Basic Open-Hearth	.61	.80	.86
Acid Open-Hearth	.62	.81	.90
Basic Electric	.62	.80	.83
Acid Electric	.66	.84	.92
Average	.63	.81	.88

Yield-Tensile Strength ratios are expressed by the formula:

Yield strength divided by tensile strength.

The strength-ductility and the strength-toughness values expressed as P-values and yield impact values show a definite improvement in quenched and tempered steels as compared to normalized and tempered steels. The data are illustrated in Table III. It may be concluded that the effect of heat treatment on TS-8130 cast steel is typical of the response of low-alloy steels to heat treatment.

Effect of Sulfur & Phosphorus on Ductility and Toughness

It is generally held that sulfur and phosphorus detract from the toughness of steel. Toughness of steel is frequently represented by impact values, especially those at sub-zero temperatures.

Published data on the effects of sulfur and phosphorus on ductility, as represented by elongation and reduction of area values, have been controversial. Some claim there is no effect and then again others believe these values are improved when the sulfur and phosphorus contents are considerably lower than the average values found in acid electric steel. It has been established in various investigations that steel made by the basic processes have lower sulfur and phosphorus contents than steel made by the acid processes. The sulfur and phosphorus contents of the basic processes and acid processes (as shown in Table I) were averaged and compared with the average ductility index values, P-values and yield-impact values as obtained from various heat treatments. The P-values and ductility index values are representative of the steel's ductility as they illustrate the relation of reduction of area and elongation to the tensile strength.

Ductility Index . . . . Ductility as represented by the ductility index (D.I.) of TS-8130 cast steels is not affected by the sulfur and phosphorus content of the steel regardless of the type of heat treatment applied. The relationship is illustrated in Fig. 2.

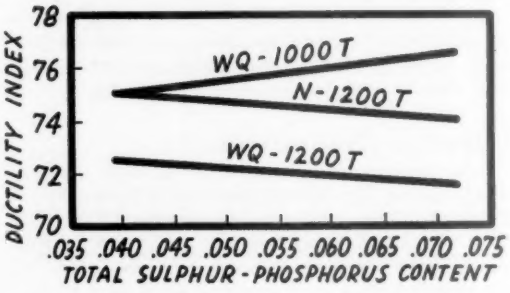


Figure 2—Ductility Index (D.I. = El. + T.S. (tan α)).

TABLE IV—The Effect of Heat Treatment on Strength-Toughness Values TS-8130 Cast Steel

Strength-Ductility Value	Normalized & Tempered at 1200°F	Water Quenched & Tempered at 1200°F
P-Value (Average)	75	84
Yield-Impact Value		
(Average) 74°F	1.80	4.3
—40°F	0.70	3.2

P-Values are expressed by the formula:

$$1/5\left[\frac{\text{Tensile Strength}}{1000} + 6\text{RA}\right]$$

Yield-Impact values are expressed by the formula:

$$\frac{\text{Yield Strength x Impact Strength}}{1{,}000{,}000}$$

The average values were obtained by substituting the data found in Table I in the above formulas.

The ductility index (D.I.) is frequently used by the British and is expressed by the formula:

D. I. = Elongation plus tensile strength times tan a D.I. = EL + TS (tan a)

Tan a equals 0.45 for quenched and tempered low-alloy steels; 0.54 for normalized and tempered low-alloy steels; and 1.00 for annealed and normalized steels.

P-Values . . . . Ductility as represented by P-values (P_V) of TS-8130 cast steel appears to be improved with lower sulfur and phosphorus contents. The effect of high sulfur and phosphorus contents seems to be more detrimental when the steel is heat treated to higher strengths. These data are illustrated in Fig. 3.

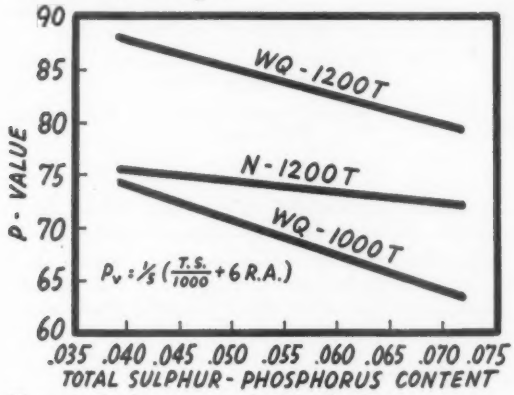


Figure 3—P-value versus total sulfur-phosphorus content.

Yield-Impact Values . . . . Toughness as represented by yield-impact values (Y.I.) definitely correlate with the sulfur-phosphorus content of TS-8130 cast steel. The lower the sulfur-phosphorus content, the greater the toughness of the steel. The effect is more pronounced in quenched and tempered steels, basic steels having nearly double the toughness of the acid steels. These data are illustrated in Fig. 4.

It may be concluded that the sulfur-phosphorus content of TS-8130 cast steel correlates with impact and reduction of area values; however, elongation data are apparently unaffected by these values. Toughness of steel definitely is affected by the kind of steelmaking process used; the basic processes have an advantage over the acid processes when specifications require added toughness in cast steel.

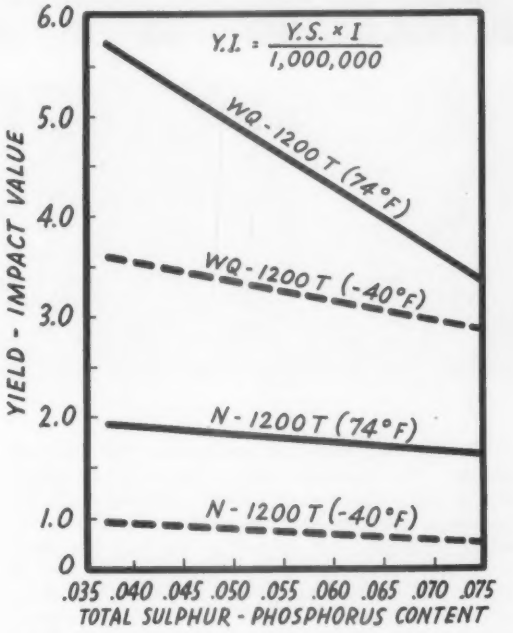


Figure 4—Yield-impact values versus total sulphur-phosphorus content.

Effect of Mass

The effect of mass on the mechanical properties of TS-8130 cast steel was determined by taking test bars from approximately the center of the one-inch and four-inch coupons produced by the acid electric process. The results are illustrated in Table IV.

It is apparent that there is no appreciable loss of tensile strength in the four-inch section as compared to the one-inch section. A significant loss of yield strength, approximately 20 percent, may be observed

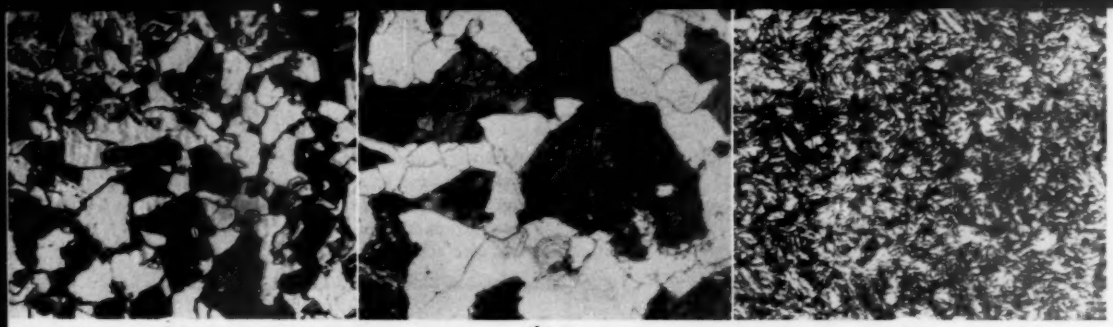
TABLE IV—EFFECT OF MASS
Mechanical Properties of TS-8130 Cast Steel Produced by Acid Electric Process

Normalize and Temper at 1200°F

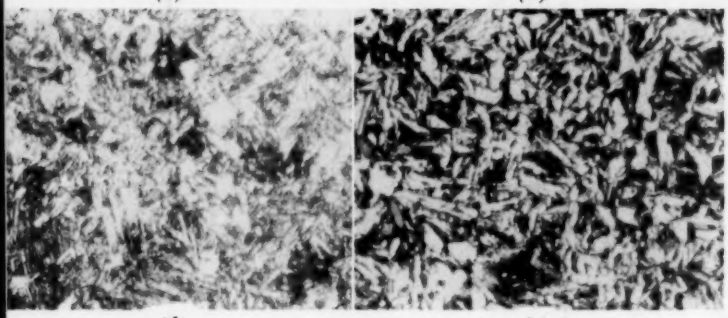
Section Size	Tensile psi	Yield psi	El. %	R.A. %	BHN	Charpy V-Notch ft.-lbs 74°F	Charpy V-Notch ft.-lbs −40°F
1 inch	95,400	63,000	22	43	192	26	7
4 inch	88,000	51,000	16	35	174	24	7

Water Quench and Temper at 1200°F

Section Size	Tensile psi	Yield psi	El. %	R.A. %	BHN	Charpy V-Notch ft.-lbs 74°F	Charpy V-Notch ft.-lbs −40°F
1 inch	114,000	96,000	18	43	235	25	23
4 inch	104,000	75,000	19	38	217	42	16



(a) (b) (c)



(d) (e)

Figure 5—Microstructures of TS-8130 Cast Steel.

(a) 1" Section Widmanstatten and blocky ferrite plus pearlite.

(b) 4" Section random blocky ferrite plus pearlite.

(c) 1" Section tempered martensite water quenched and tempered at 1200° F.

(d) 1" Section tempered martensite water quenched and tempered at 1000° F.

(e) 4" Section tempered martensite, fine pearlite, Widmanstatten, ferrite

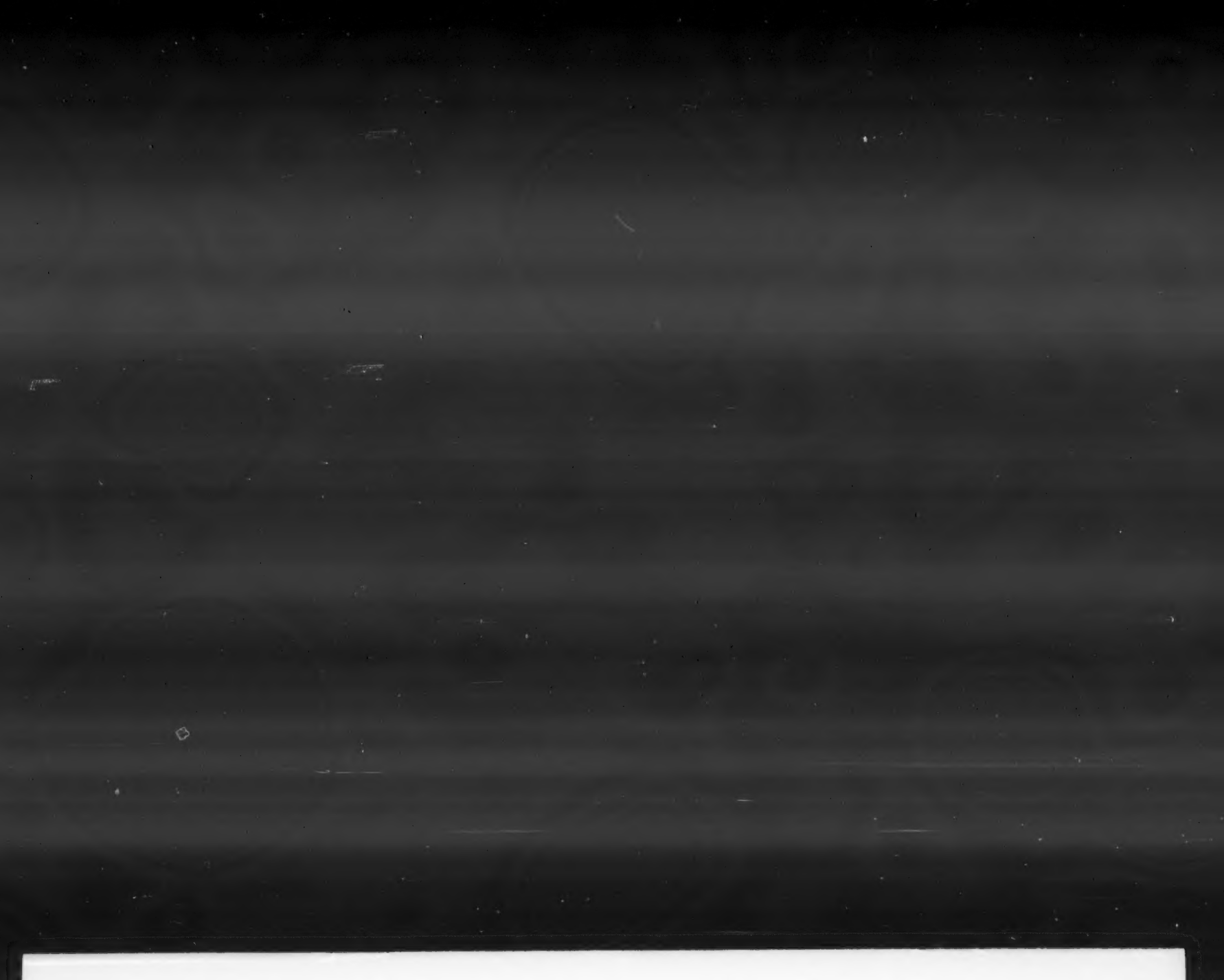
in the four-inch section as compared to the one-inch section. The ductility values, elongation and reduction of area, also showed a loss of approximately 20 percent in the four-inch section when in the normalized condition. Of interest is the fact that there is no appreciable loss in ductility when the steel is in the quenched and tempered condition. The effect of mass apparently has little effect on the impact values obtained when the steel is in the normalized state. The large variation found in impact values when the steel had been quenched and tempered suggests that possibly the sample specimens for testing were taken in a plane of centerline weakness.

Microstructure

Metallographic specimens were cut from the broken tensile bars of the acid electric heat for all heat treated conditions and section sizes. The microstructures are typical of what may be expected from a steel of a given hardenability subjected to various cooling rates.

The observed microstructures confirm the mechanical properties obtained and correlate well with the findings in SFSA Research Report No. 16, "Weldability of Carbon-Manganese Steels." For example, the random blocky ferrite plus pearlite found only in the four-inch section illustrates the reason for the lower strength and ductility in this section as compared to the one-inch section. Research Report No. 16 states that the lowest mechanical properties are obtained when random blocky ferrite plus pearlite is present. The refinement in microstructure for improved mechanical properties can only be obtained by applying faster cooling rates. Thus the four-inch section, on being water quenched, did not have random blocky ferrite plus pearlite as its microstructure and consequently showed improved mechanical properties in relation to the one-inch section as compared to the same samples heat treated to the normalized and tempered condition.

The microstructure obtained from various heat treatments may be seen in Figure 5. The microstructures of the other three TS-8130 steels were similar to those shown in Fig. 5.

Conclusions

1. The high strengths with corresponding added toughness and ductility obtained when heat treating TS-8130 cast steel indicate that it may be used successfully in place of the usual low-alloy cast steels.
2. Uniform hardenability and mechanical properties may be obtained regardless of the type of steelmaking process employed.
3. Added strength-toughness ratios may be obtained by the use of water quenching in place of air quenching.
4. The sulfur-phosphorus content has a decided effect on the value of impact properties obtained. In this instance, when added toughness is required in the steel, the basic processes have an advantage over the acid processes.
5. The difference in mechanical properties between one-inch and four-inch sections indicated that the mass effect was relatively small provided that the four-inch section was given a suitable cooling rate. There is one exception, and that is that the yield strength appears to be affected by mass to the extent of approximately a 20 percent loss of strength in a four-inch section.
6. The lower mechanical properties obtained in four-inch section result from random blocky ferrite plus pearlite as the result of slower cooling rates because of mass effect may be improved by water quenching.